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DATA REPORT FOR WIND TUNNEL TESTS
OF APOLLO MODEL FS-4 IN
THE AEDC HOTSHOT II.

NAS 9-150

(U)

24 August 1962 4.5.5.1

D. J. Gildea - Manager
Flight Technology

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FOREWORD

The tests described herein were conducted at the Arnold Center Von Karman Facility Hotshot II Wind Tunnel, Arnold Air Force Station, Tennessee, during the period from 2 July to 17 July, 1962.

This report was prepared by M. H. Cohen of the Wind Tunnel Projects Group, Los Angeles Division.

[redacted]

ABSTRACT

Force tests of a 0.04-scale model (FS-4) of the Apollo command module were conducted in the Von Karman Facility Hotshot II Tunnel at a Mach number of approximately 18.7.

This report presents basic wind tunnel test data only, in order to make the test results available at the earliest possible date. Analyses and summary of results will be reported later under separate cover.

[redacted]

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I. INTRODUCTION

Hypervelocity wind tunnel tests of the 0.04-scale Apollo force model FS-4 were conducted to investigate stability characteristics of the command module in the re-entry position. The tests were conducted at approximately the following tunnel conditions:

Mach Number = 18.7
Reynolds Number = 8.5×10^4 (based on diameter)
Velocity = 9,000 ft/sec.
Reservoir Temp. = 3500°K

The model was tested over an angle of attack range of 120° to 180°.

Pretest information was given in Reference (a).

II. REMARKS

During the first run, the model internal support structure yielded permitting the model shell to move with relation to the balance. A backup model was available, and was reinforced to prevent recurrence of the failure.

The balance first installed in the model exhibited excessive zero shift on the axial force gage. A different balance was installed which gave improved results for several runs, although the accelerometers which are supposed to compensate balance outputs caused by sting vibration did not function very well. The original balance was then reworked to reduce the zero shift and installed in the model. This gave better results than the alternate balance, and was used for the remainder of the test.

The AEDC personnel quoted a data tolerance equal to ±5% of the balance rated loads on the measured balance outputs. This error of ±5% on the output from each balance element results in the following probable errors in final coefficients:

$C_N = .092$	$C_L = .114$
$C_A = .121$	$C_D = .100$
$C_{m_A} = .064$	$C_{m_{cg}} = .091$

The data obtained during these tests were compared to data obtained in the JPL 21" HWT at M = 9.0. The root-mean-square difference between the Hotshot II data and the faired JPL data are as follows:

$C_N = .030$	$C_L = .033$
$C_A = .052$	$C_D = .050$
$C_{m_A} = .017$	$C_{m_{cg}} = .002$

[redacted]

III. MODEL DESCRIPTION

A. General

The command module is a body of revolution consisting of a conical nose, the apex of which is terminated in a spherical tip, and a spherical heat shield. The nose cone is faired into the heat shield by a corner radius.

Model construction consists of a Fiberglass shell, reinforced by magnesium structure which also provides attachment for the balance block. Flush, screw-in type plugs are provided for access holes necessary to reach balance-mounting screws and pressure tube connections. The balance mounts in the model at an angle of 150°.

Structural integrity of the model is investigated in Reference (b).

B. Model Nomenclature and Full Scale Dimensions

Command Module, C2 (Dwg. No. 7121-01098)

Maximum diameter, in.	154.00
Radius of spherical heat shield, in.	184.80
Corner radius, in.	7.70
Nose cone semi-angle, deg.	33.00
Nose cone vertex radius, in.	9.13

[redacted]

IV. TEST PROCEDURE

A. Test Nomenclature

A = Axial Force, lb. Positive in aft direction.

C_A = Axial Force Coefficient = A/qS_π

C_D = Drag Coefficient = D/qS_π

C_L = Lift Coefficient = L/qS_π

C_{m_A} = Pitching Moment Coefficient, referred to apex of nose cone = $m_A/qS_\pi d$

$C_{m_{cg}}$ = Pitching Moment Coefficient, referred to reference center of gravity = $m_{cg}/qS_\pi d$

C_N = Normal Force Coefficient = N/qS_π

d = Maximum diameter of command module, in.

D = Drag, lb. Positive in downstream direction.

L = Lift, lb. Positive upward, normal to freestream direction.

m_A = Pitching Moment about apex of nose cone, in-lb. Positive in direction which increases α.

m_{cg} = Pitching Moment about reference c.g., in-lb. Positive in direction which increases α.

M = Mach Number

N = Normal Force, lb. Positive in upward direction when $\alpha = 0°$.

p = Pressure, psi.

q = Dynamic pressure, psi.

U = Velocity, fps

T = Temperature, °K

[redacted]

IV. TEST PROCEDURE - continued

A. Test Nomenclature - continued

RN = Reynolds Number based on diameter "d".

S_π = Reference area = Area of circle of diameter "d".

Xcp = Distance from nose cone apex to intersection of resultant force vector with model axis of symmetry, in. Positive in forward direction.

$\bar{x}$ = Distance from nose cone apex to reference c.g. along model axis of symmetry, in.

$\bar{z}$ = Distance from model axis of symmetry to reference c.g., in.

α = Angle of attack, deg. = angle between nose cone end of axis of symmetry and the relative wind vector.

α_s = Sector or support angle, deg.

α_o = Offset angle, deg.

θ = Angle between balance axis and model axis of symmetry. $\theta = 0°$ with nose cone end of model aligned with forward end of balance axis, and is positive when model angle of attack is greater than balance angle of attack, deg.

Subscripts and Superscripts

BAL - Refers to balance axis

1 - freestream conditions

o - stagnation conditions

( )' - conditions just downstream of normal shock

IV. TEST PROCEDURE - continued

B. Model Installation

The FS-4 model was initially installed on the VKF 3-6 three-component force balance with its associated sting, supported in a 20° offset adapter by the Hotshot II model support system. A complete description of the facility and its operation is given in Reference (c).

A sketch of the installation is given in Figure 2, and a photograph of the model installed in the tunnel is presented in Figures 3 and 4.

C. Instrumentation

1. Balance

The VKF 3-6 balance used AB-32 resistance strain gages, on cantilever beams, as sensing elements. Accelerometers, in the form of gaged cantilever beams similar to the force elements, were arranged to compensate for low-frequency sting oscillations in the normal-force direction. The output signals from the force elements were fed through low-pass resistance-capacitance filters with a cutoff frequency of about 200 cps, amplified by a C.E.C. carrier amplifier, and recorded on a C.E.C. oscillograph. Both compensated and uncompensated signals were recorded.

For the first few runs, the compensation in the above balance was inadequate, and the axial force gage showed an excessive zero shift. The 3-5 balance was then installed. This was identical to the 3-6 balance described above except that the accelerometer sensing elements were variable reluctance coils. While this balance was in use, the 3-6 balance was reworked to minimize the axial force zero shift, and much stiffer accelerometers were installed, using semiconductor strain gages as sensing elements. This gave better results than either of the other arrangements.

[redacted]

IV. TEST PROCEDURE - continued

C. Instrumentation - continued

2. Pressure Measurements

A 3 psid wafer-type pressure transducer was mounted in the model and connected to one of two orifices in the heat shield face of the model. This transducer was used to measure P_{t2} at the model location as a check on two pitot probes, located one above and one below the model on the vertical center line of the tunnel. These probes also incorporated 3 psid wafer gages. The output signals from the three transducers were recorded on a C.E.C. oscillograph.

3. Contamination Instrumentation

The present state of Hotshot tunnel development requires that the level of contamination in the flow be monitored continually. Contamination originates in the arc chamber, where particles of the electrodes and insulation are eroded by the action of the arc. A discussion of the problem and means of controlling it is contained in Reference (c).

In order to monitor the amount of contamination in the flow, three types of instrumentation were used. First, two heat-transfer probes were installed near the two pitot probes. They each consisted of a 0.5-inch radius hemisphere-cylinder, with one thermocouple calorimeter gage at the stagnation point, and another at the shoulder. It is assumed that only the stagnation region heat transfer measurement is affected by flow contamination. Stagnation region heat transfer was computed from the shoulder gage measurements, and this was compared with the rate measured by the stagnation point gage. A difference greater than the normal error in measurement indicates the presence of contamination. In addition, a theoretical stagnation point heat transfer rate was computed for comparison with that measured.

IV. TEST PROCEDURE - continued

C. Instrumentation - continued

The second type of contamination monitor consisted of a target plate, located near the bottom of the test section, which was weighed before and after each blow. An increase in weight would indicate contamination particle impingement on the plate.

The third set of monitoring instrumentation was a photoelectric cell located outside the test section schlieren window. A light source on the opposite side of the tunnel was focused on the cell. Any contamination passing through the test section would diminish the amount of light striking the photocell, thereby changing its output level. A second photocell was used to monitor the luminosity of the gas in the test section to provide a correction to the output of the first photocell.

Output signals from both photocells and from the heat transfer gages mentioned previously were recorded on a C.E.C. oscillograph.

[redacted]

IV. TEST PROCEDURE - continued

D. Data Reduction Equations

Rotation from balance axis to body axis system:

$$C_N = -C_{N_{BAL}} \cos \theta + C_{A_{BAL}} \sin \theta$$

$$C_A = C_{N_{BAL}} \sin \theta + C_{A_{BAL}} \cos \theta$$

$$X_{cp}/d = C_{m_A}/C_N$$

Angle of Attack:

$$\alpha = \theta - \alpha_o - \alpha_s$$

Rotation from body axis to stability axis system:

$$C_L = C_N \cos \alpha - C_A \sin \alpha$$

$$C_D = C_A \cos \alpha + C_N \sin \alpha$$

$$C_{m_{cg}} = C_{m_A} + C_N (\bar{x}/d) + C_A (\bar{z}/d)$$

Geometric Constants:

$S = 29.8025$ in.^{2}

$d = 6.160$ in.

$\theta = 150°$

$\bar{x} = 4.2276$ in.

$\bar{z} = 0.3634$ in.

$\alpha_o = +10°$ for $\alpha = 150°$ to $180°$

$-20°$ for $\alpha = 120°$ to $150°$

Test Section Conditions:

Equations for determining flow conditions in the test section are given in Reference (d).

 [redacted]

[redacted]

V. REFERENCES

(a) SID-62-424, "Pretest Report for Apollo Force Model FS-4 in the Arnold Center VKF Hotshot II", 3 April 1962.

(b) SID-62-331, "Structural Analysis of the .040 Scale Apollo Wind Tunnel Models FS-4 and PS-4", 2 April 1962.

(c) AEDC-TN-60-222, "Development of Capacitance and Inductance Driven Hotshot Tunnels", Lukasiewicz, Harris, Jackson, van der Bliek, and Miller; January 1961.

(d) AEDC-TN-61-82, "Determination of Test-Section, After-Shock, and Stagnation Conditions in Hotshot Tunnels Using Real Nitrogen at Temperatures from 3000 to 4000°K.", Grabau, Humphrey, and Little; July 1961.

[redacted]

APPENDIX "A"

[redacted]

RUN INDEX

Configuration for all runs: C_2

Average Test Conditions:

Mach Number	18.73
Static Pressure	.0014 psia
Dynamic Pressure	.348 psi
Reynolds Number	85,000

Run	Angle of Attack
1256	180°
1257	160°
1259	150°
1260	140°
1261	130°
1263	120°
1264	170°

NASA-NAA APOLLO FORCE TEST - HOTSHOT II

[redacted] S-4 Command Module

Force and Moment Coefficients tabulated with angle of attack

Run Number	Nominal Angle of Attack	(AVG.) C_A	(AVG.) C_N	(AVG.) C_{m_A}	(AVG.) $\frac{X_{cp}}{d}$	(AVG.) C_D	(AVG.) C_L	(AVG.) $C_{m_{c.g.}}$	Free-stream Conditions (AVG.) P_1, psia	(AVG.) U_1, fps	(AVG.) q_1, psia	(AVG.) M_1	(AVG.) RN_{MODEL}	Stagnation Conditions (AVG.) $P_{o,max}$, psia	(AVG.) $T_{o,max}$ °K	(AVG.) P_o', psia	(AVG.) P_o'/P_o
1256	180°	-1.470	.007	-.019	—	1.470	.007	-.101	.0014421	8830.	.353	18.70	82,510.	10,513.	3,818.	.658	$.9957 \times 10^{-4}$
1264	170°	-1.448	-.018	+.017	—	1.423	.269	-.078	.0014709	8773.	.359	18.66	85,173.	9,988.	3,615.	.687	1.0113 "
1257	160°	-1.369	.080	-.011	-.1375	1.314	.394	-.037	.0012154	8379.	.306	18.96	85,968.	9,618.	3,482.	.569	1.0032 "
1259	150°	-1.135	.136	-.036	-.2630	1.051	.449	-.009	.0015372	8475.	.367	18.48	94,648.	9,990.	3,622.	.683	1.1193 "
1260	140°	-.995	.188	-.062	-.3340	.901	.506	.008	.0014093	9054.	.348	18.80	76,200.	10,787.	3,905.	.649	.9482 "
1261	130°	-.727	.262	-.112	-.4470	.668	.389	.024	.0012952	8636.	.324	18.87	82,246.	10,183.	3,691.	.602	.9801 "
1263	120°	-.469	.328	-.166	-.5050	.519	.243	.032	.0016375	9806.	.392	18.50	65,178.	12,011.	4,368.	.731	.9303 "

PRELIMINARY
DATA

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APPENDIX "B"

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INDEX OF FIGURES

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Figure 1 - Diagram of Model and Reference Systems

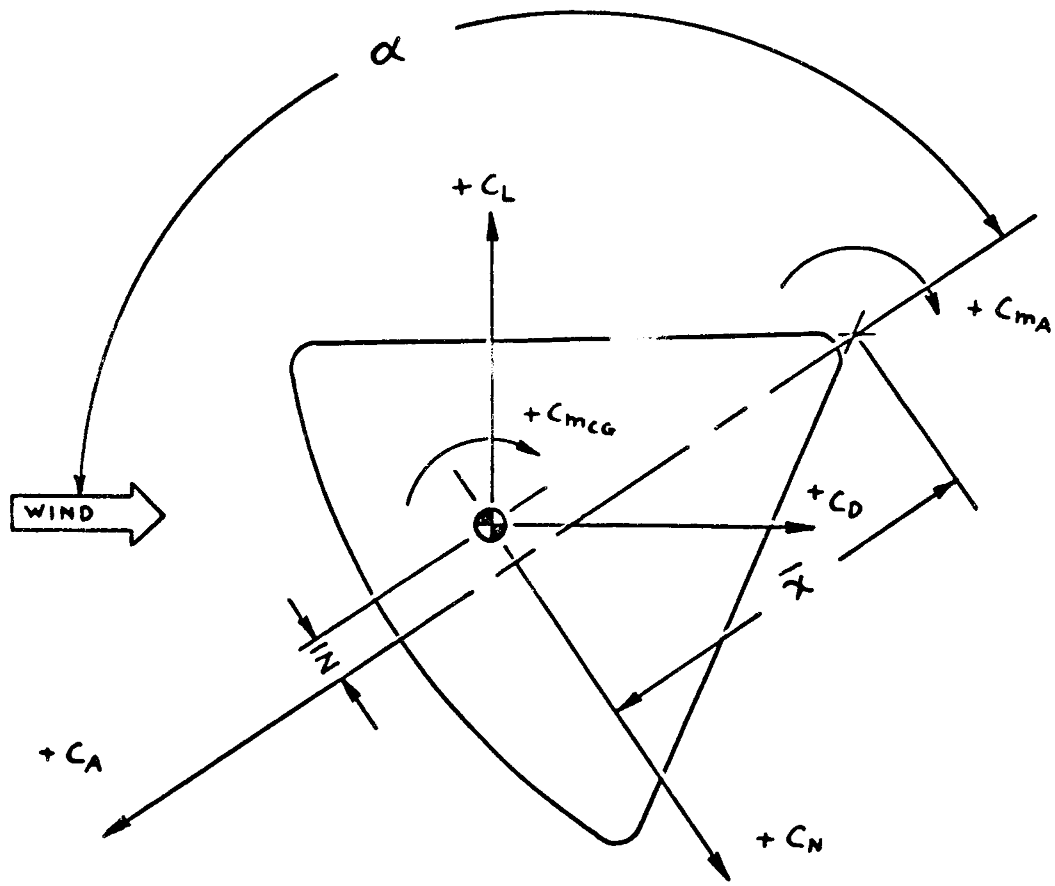

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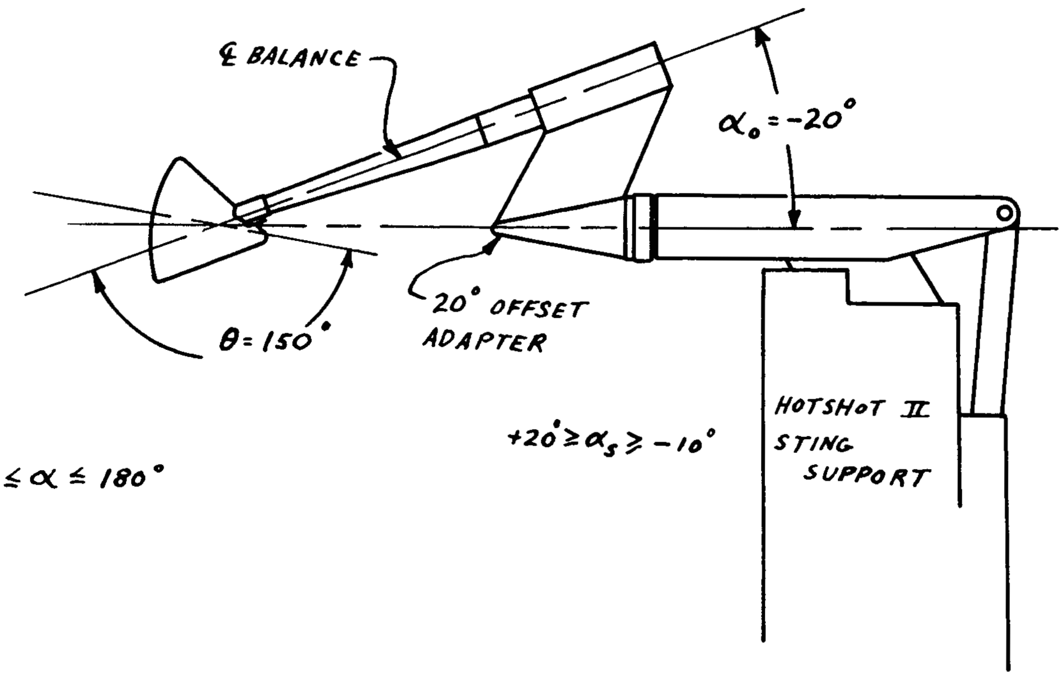
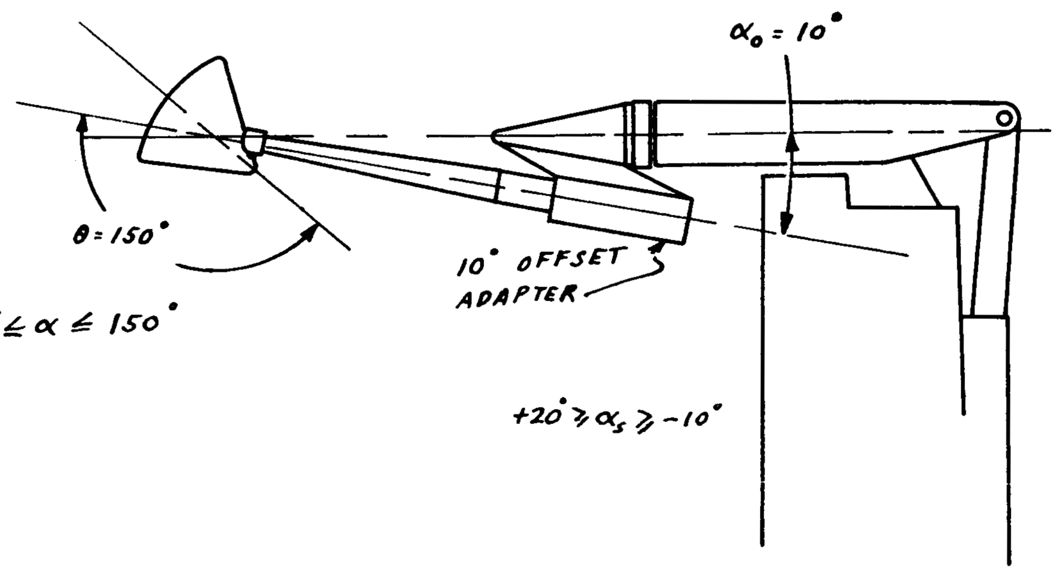
Figure 2 - Installation Sketch



$150° \leq \alpha \leq 180°$



$120° \leq \alpha \leq 150°$

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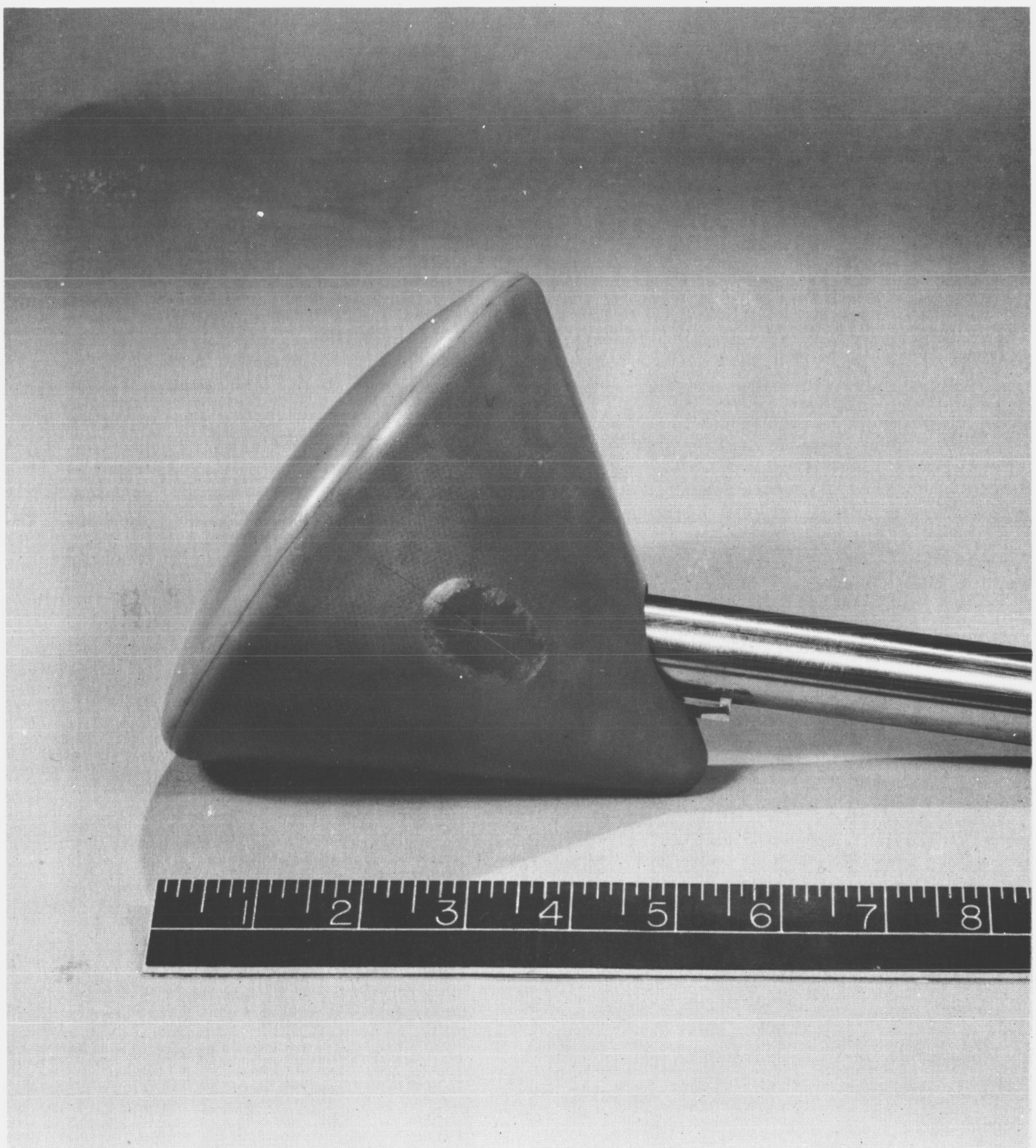

Figure 3 - Closeup of Model on Dummy Balance

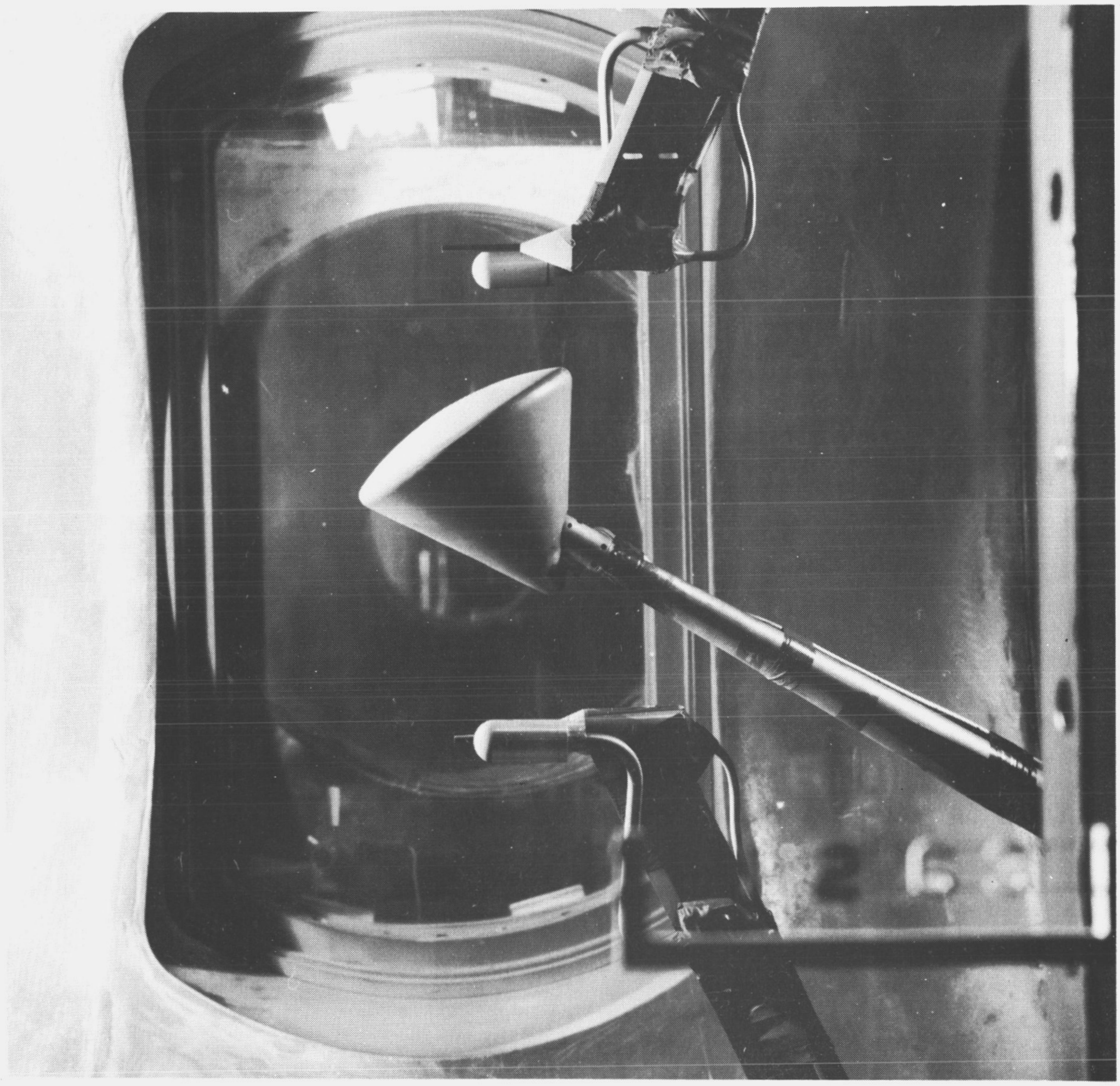

Figure 4 - Side View of Model in Tunnel, α = 120°

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Figure 5 - Front View of Model in Tunnel, $\alpha = 120°$

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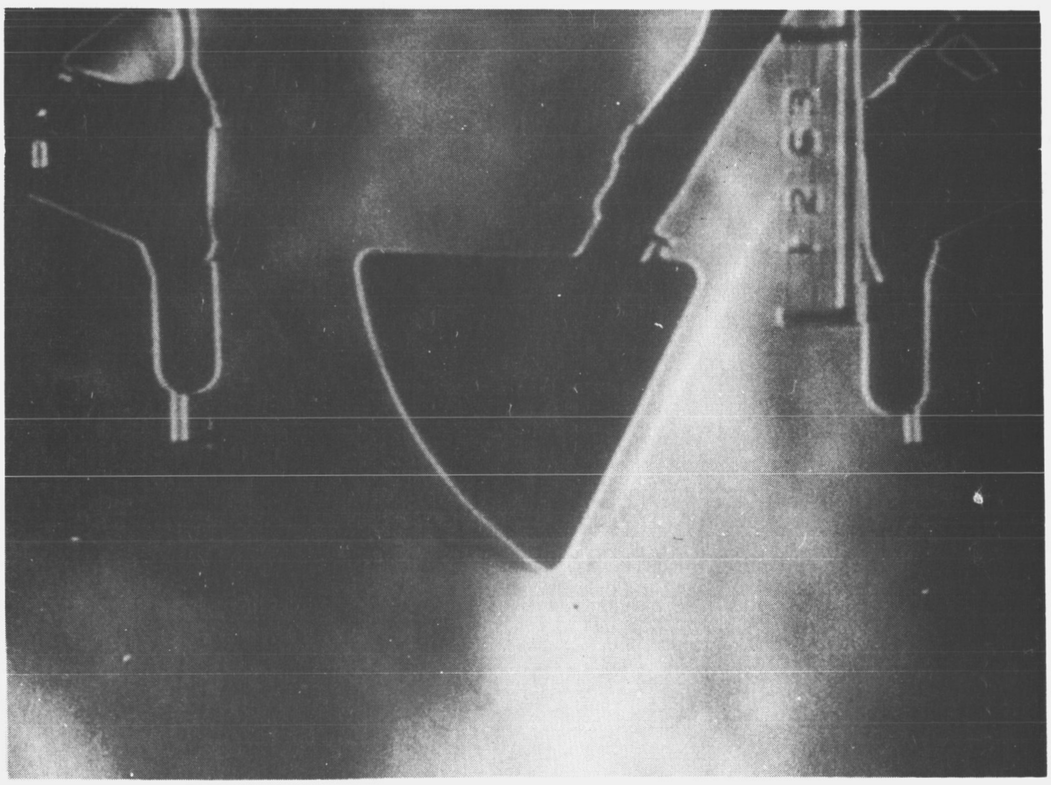

Figure 6 - α = 120°

Figure 7 - α = 130°

Schlieren Photos

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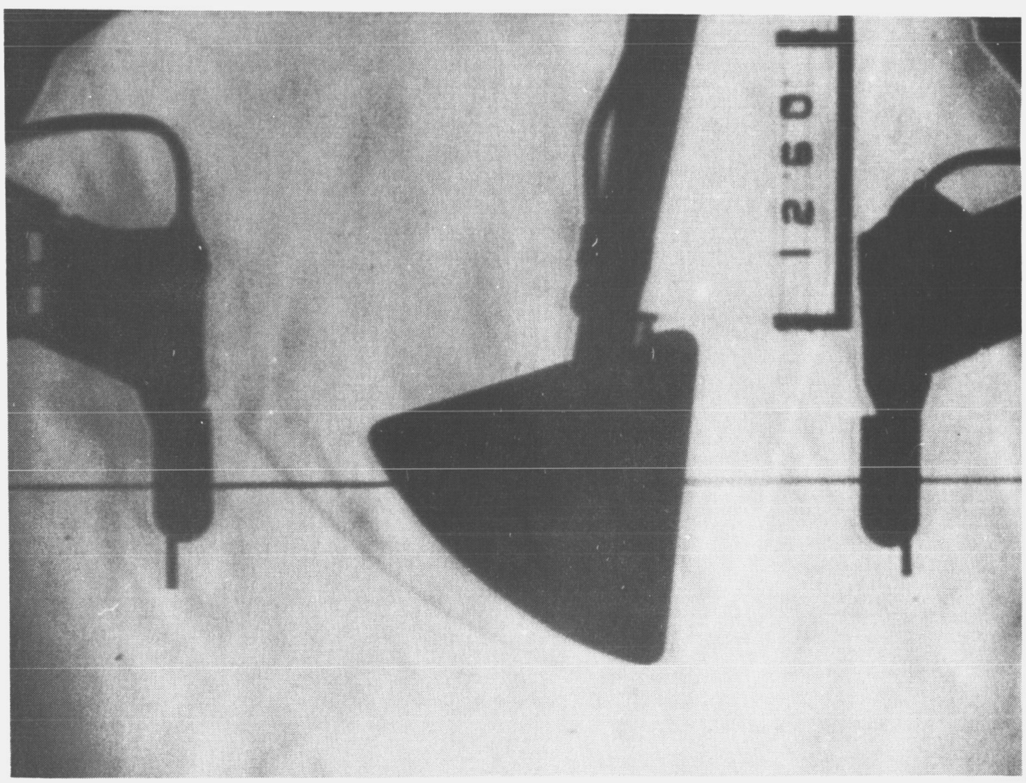

Figure 8 - $\alpha = 140°$

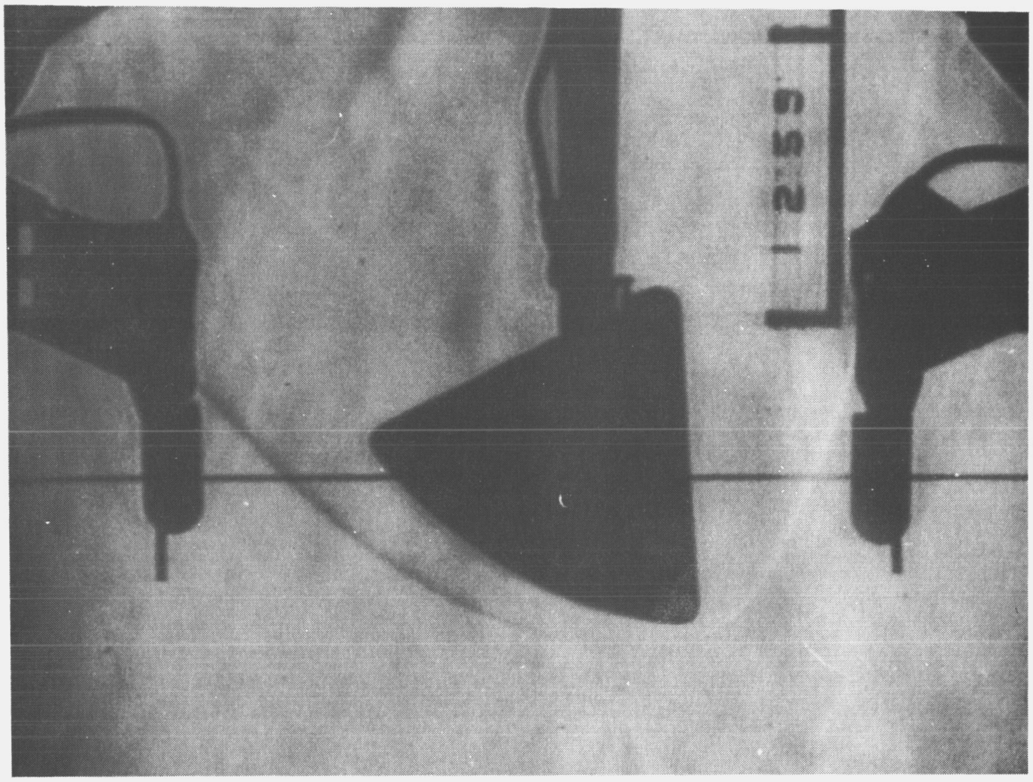

Figure 9 - $\alpha = 150°$

Schlieren Photos

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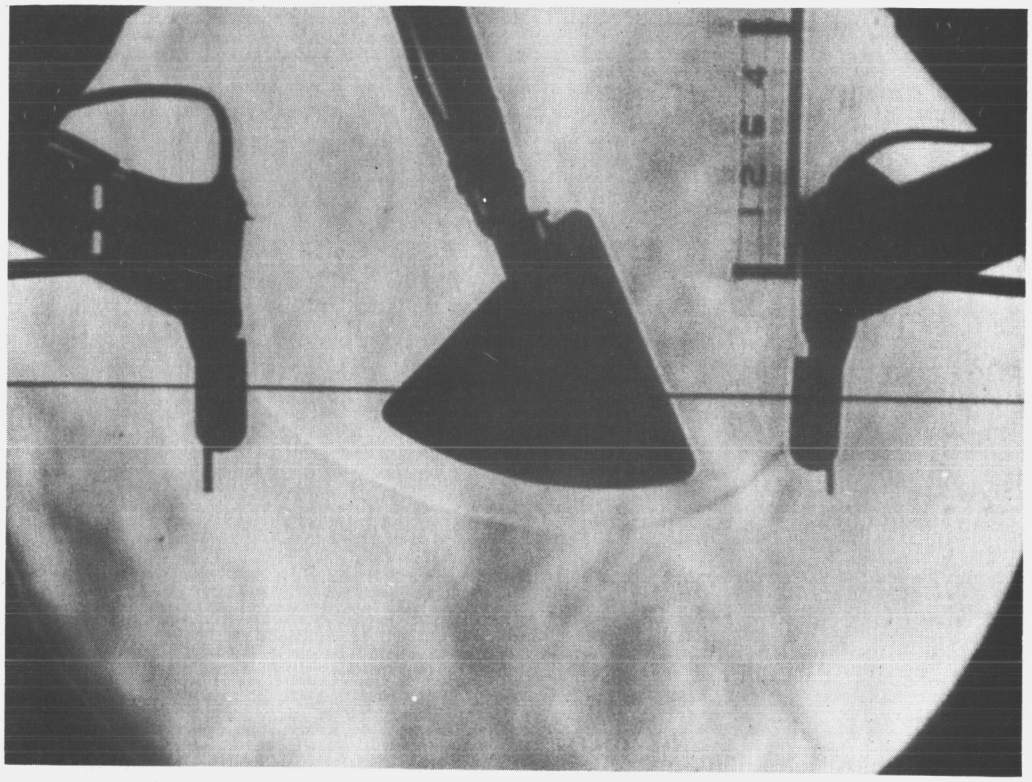

Figure 11 - α = 170°

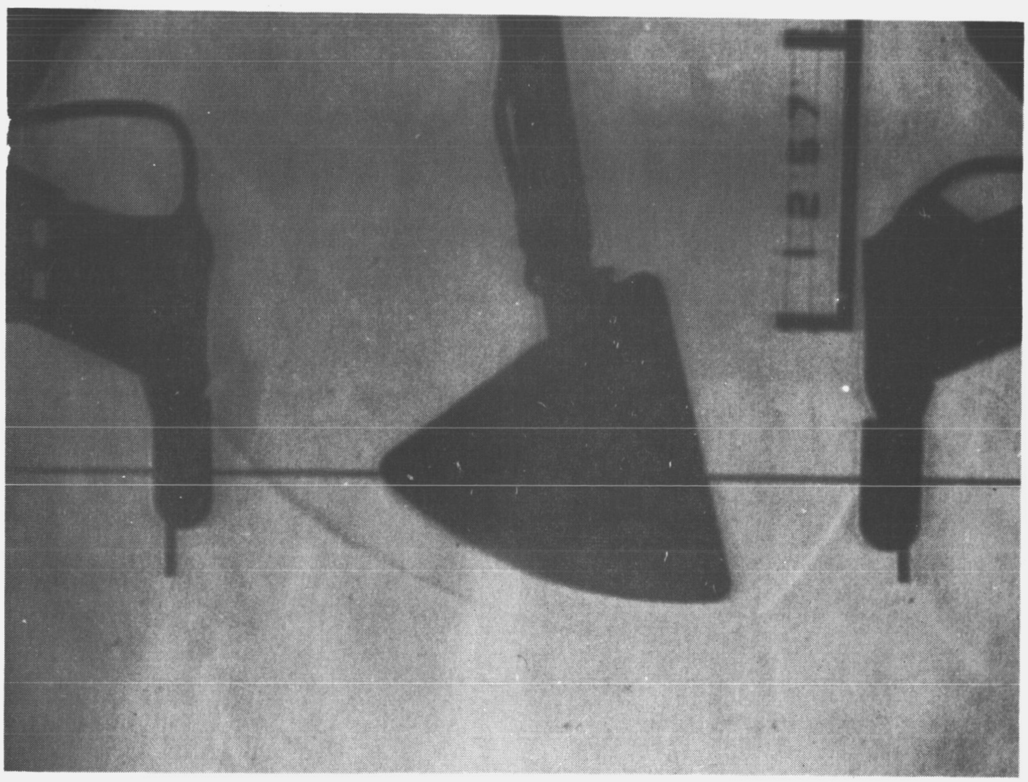

Figure 10 - α = 160°

Schlieren Photos

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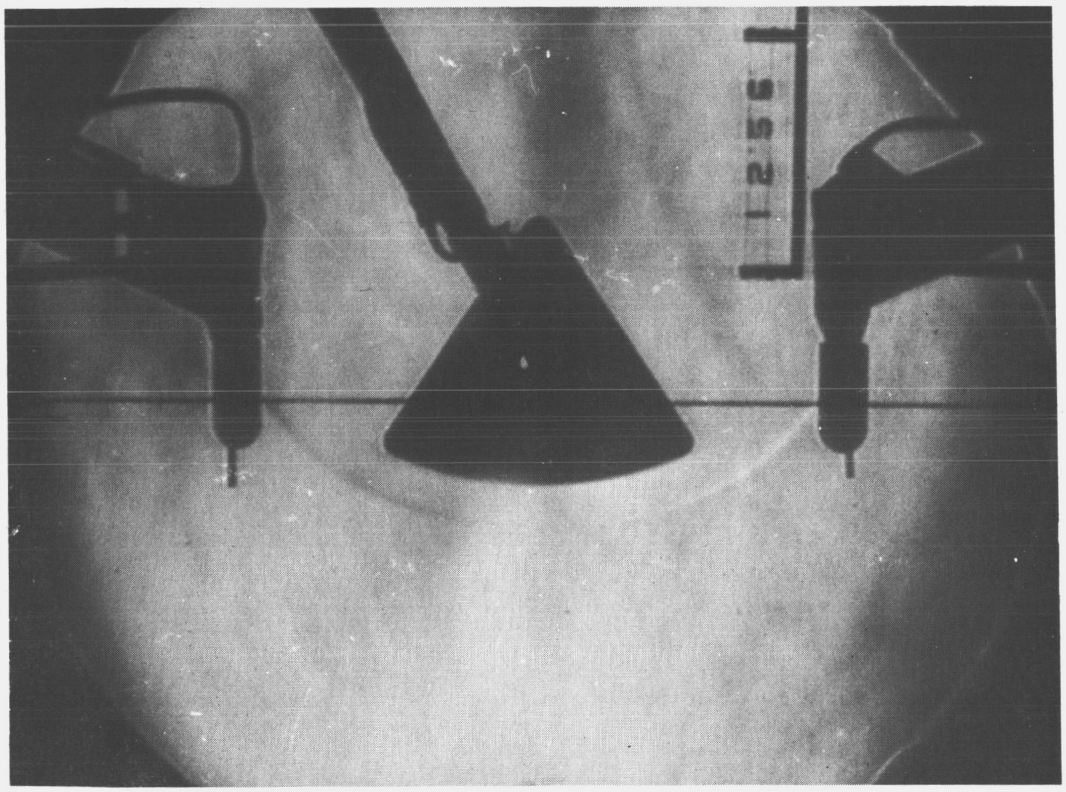

Figure 12 - α = 180°

Schlieren Photos

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FIG. 13a

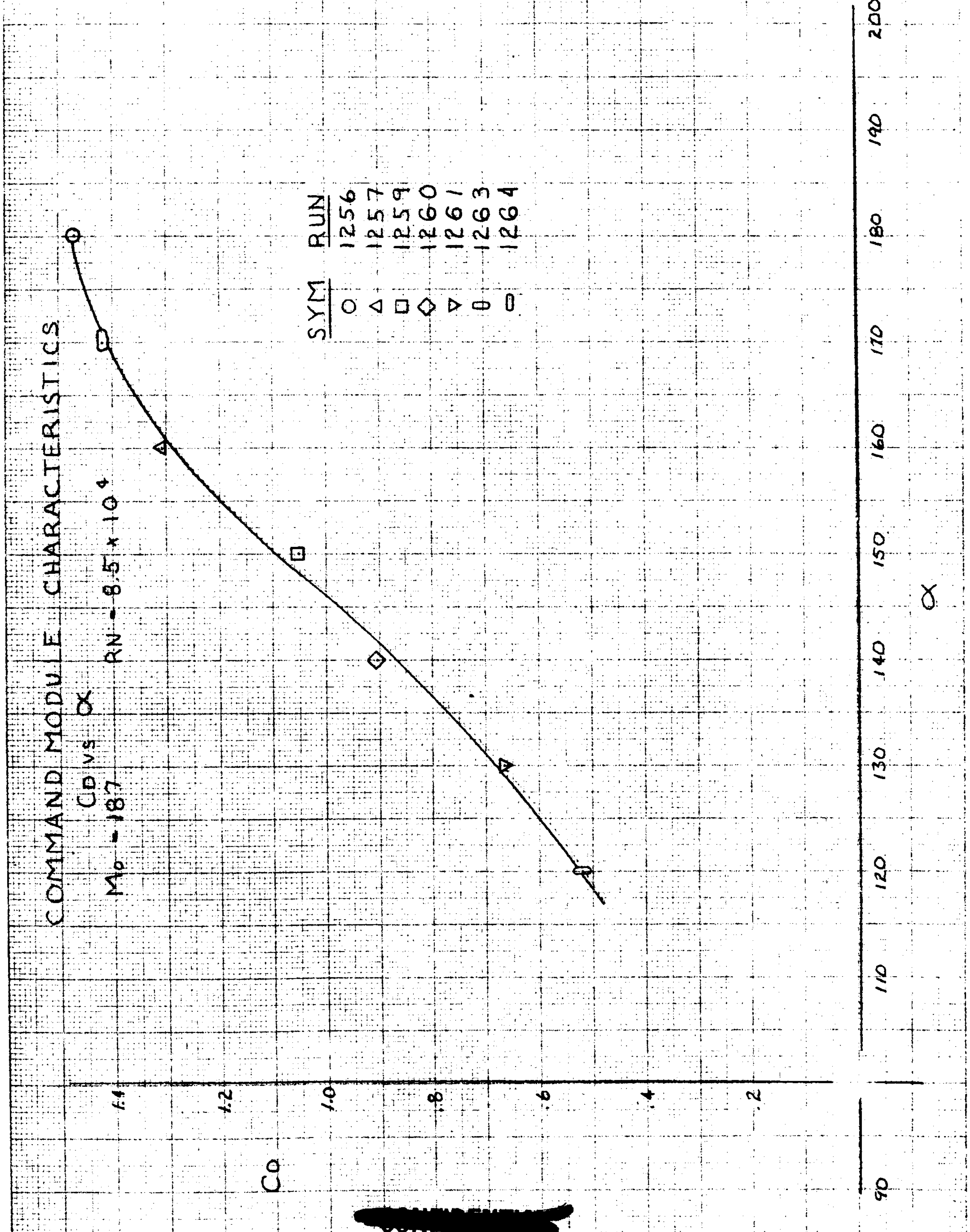

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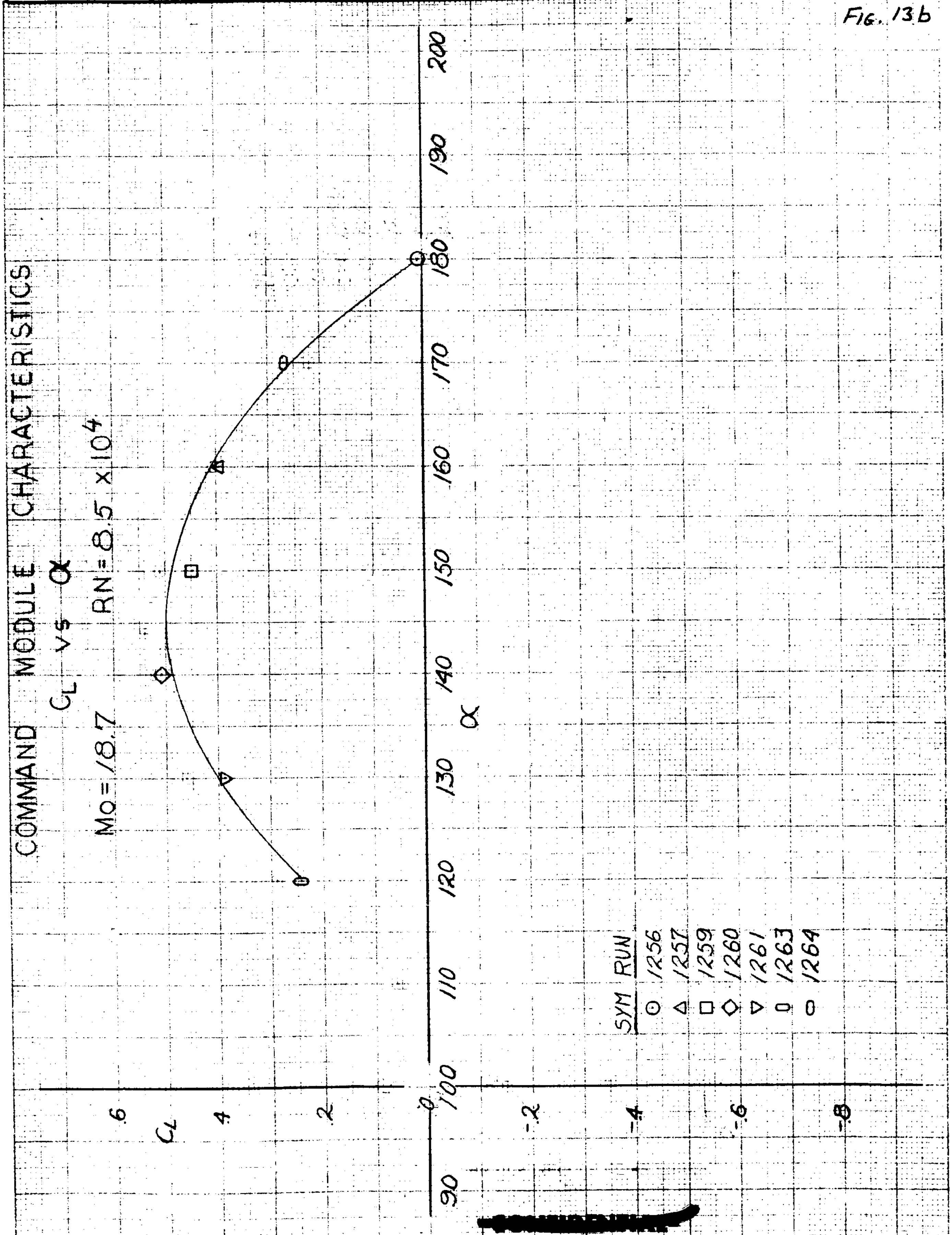
Fig. 13b



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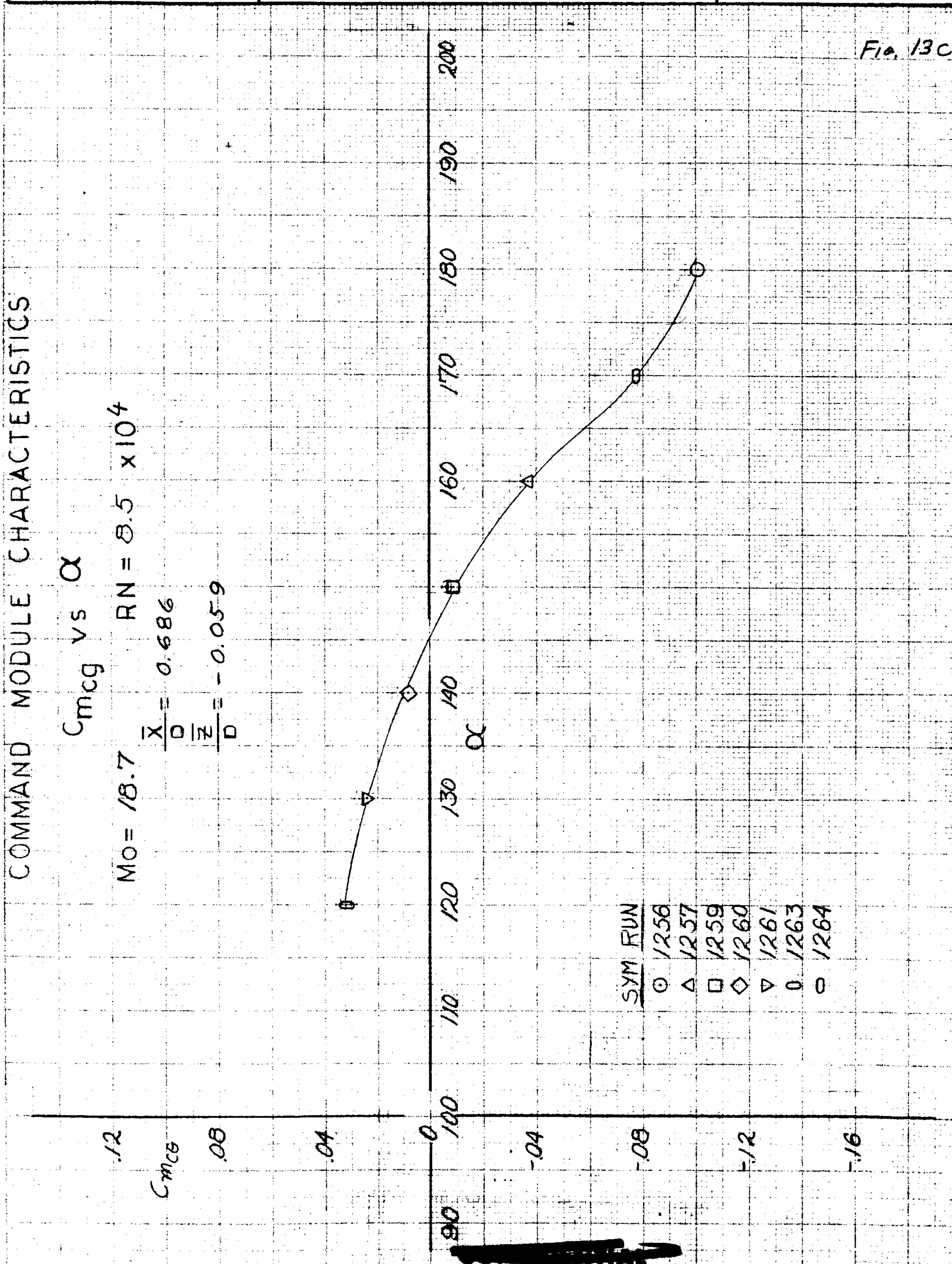

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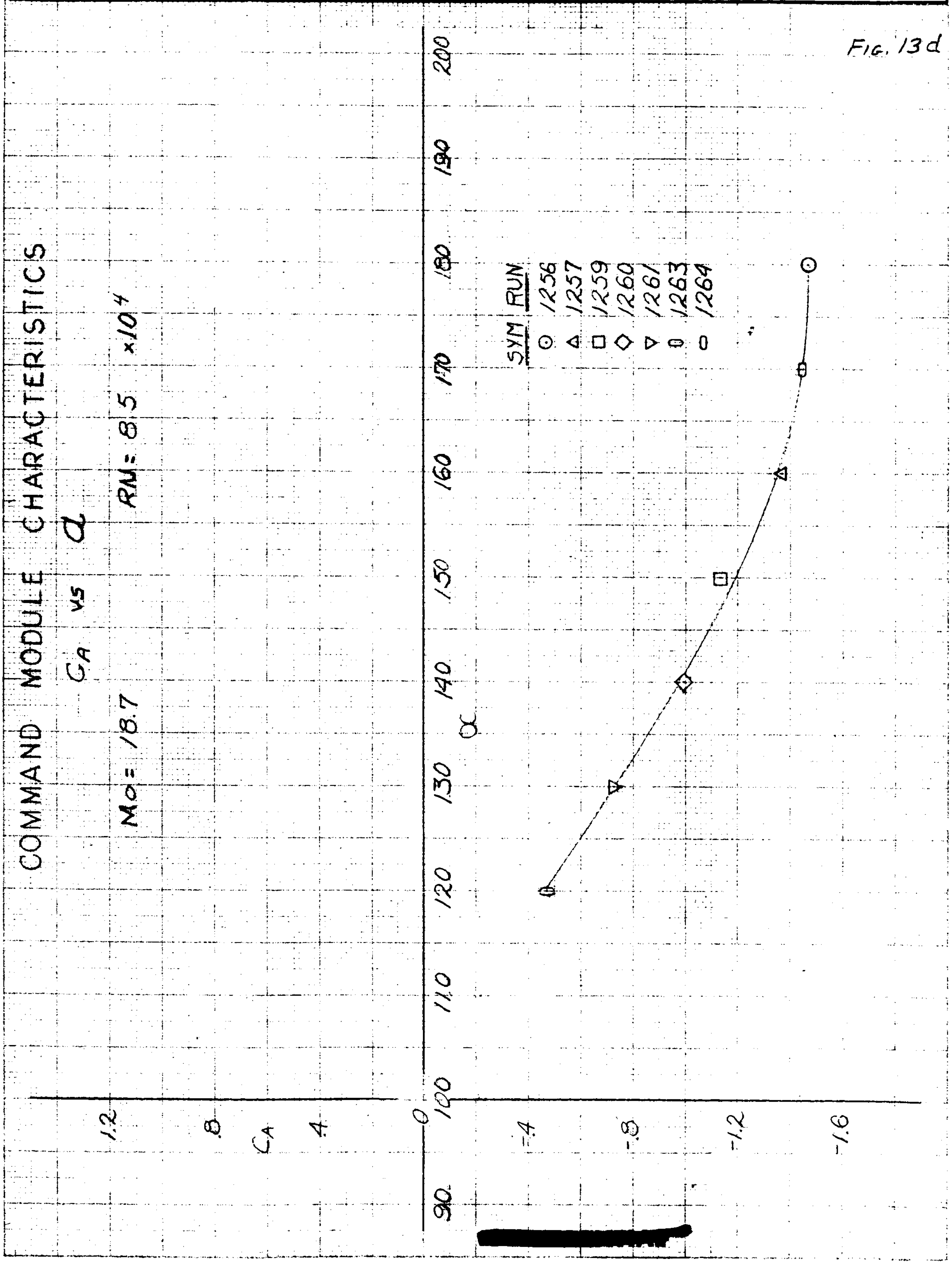

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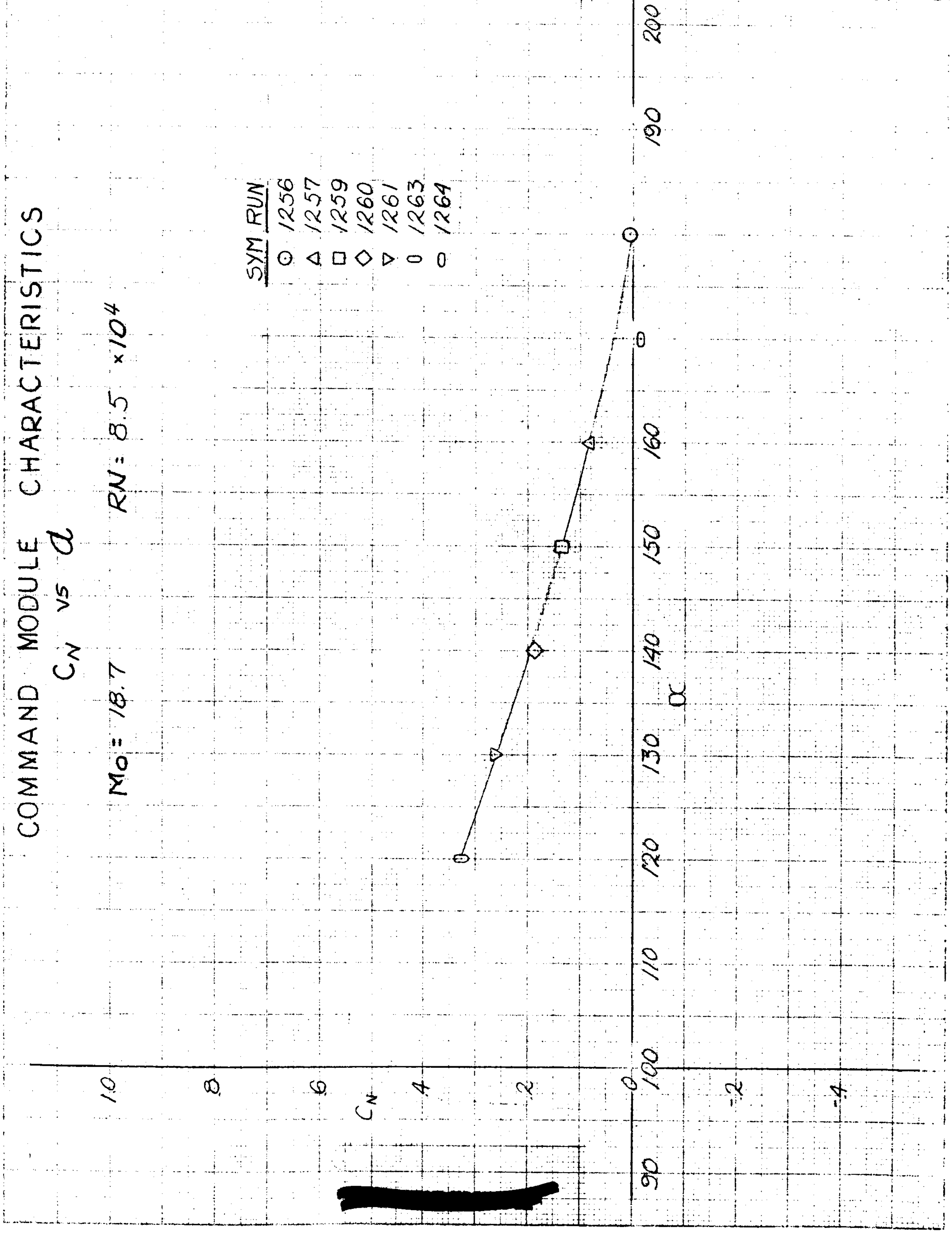
FIG. 13e



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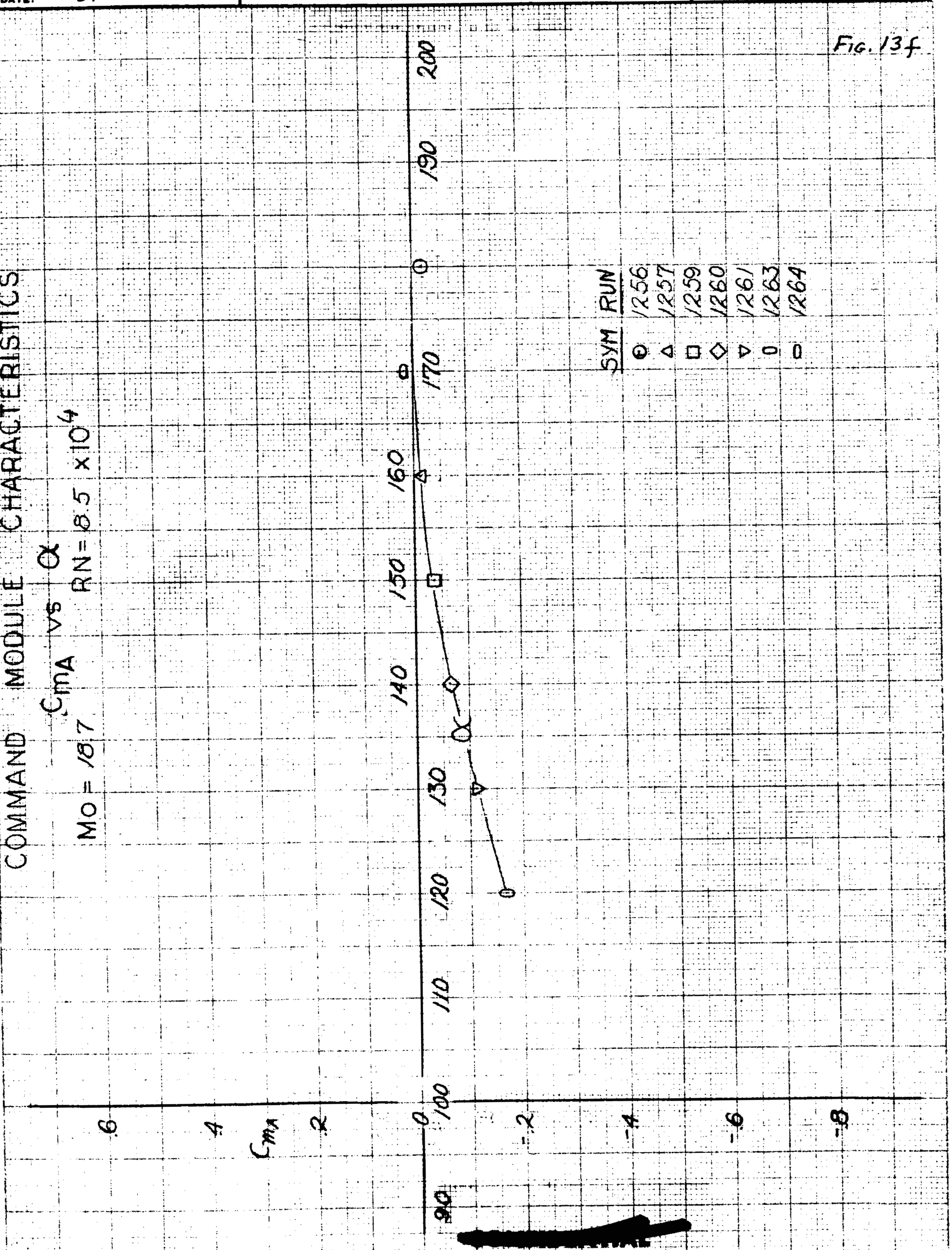

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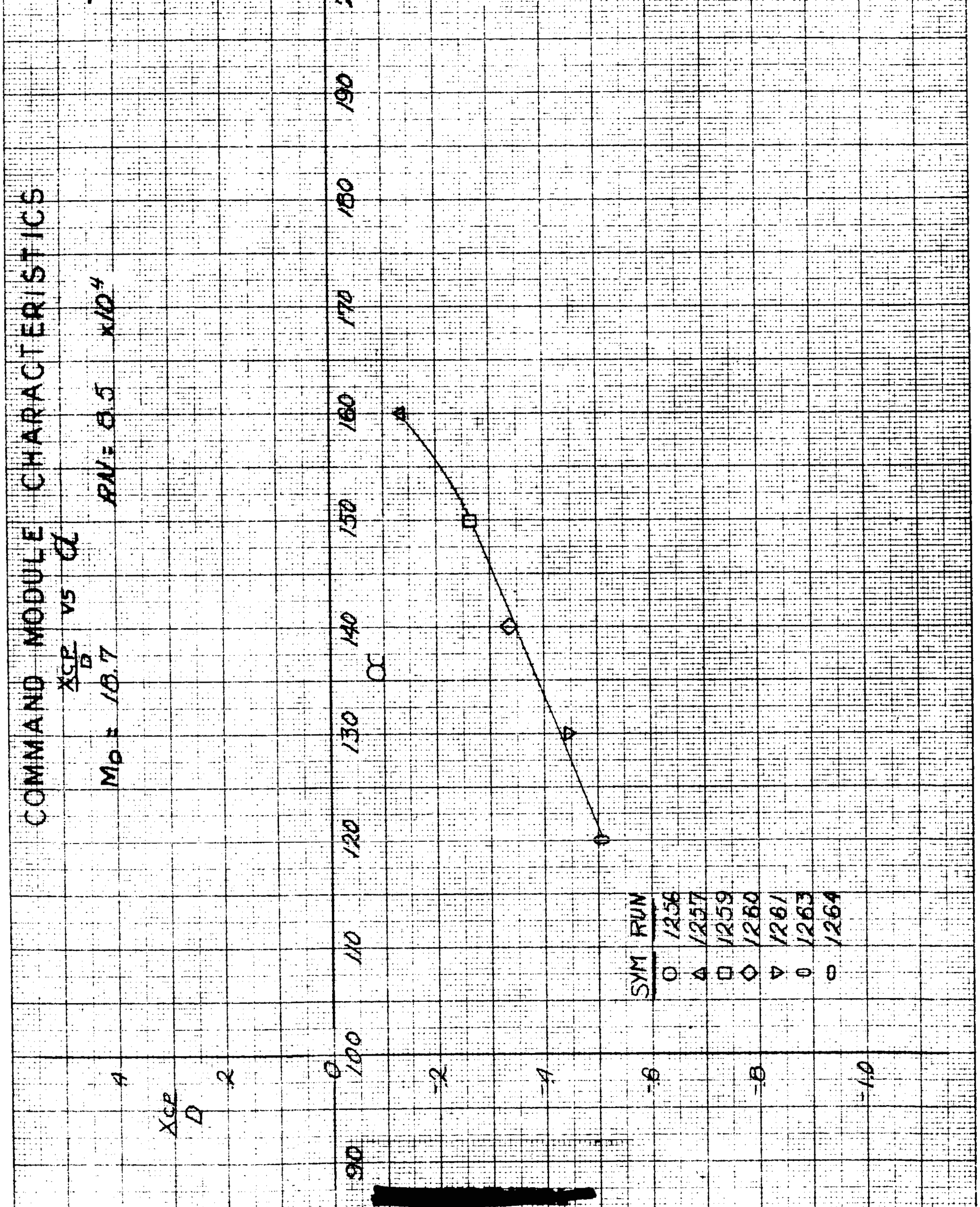
Fig. 13g



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